ENGINEERING STUDY

ON

WIND-TUNNEL

FAN-BLADE MATERIALS

By

Edwin C. Kilgore
Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Virginia

1956

I. In selecting satisfactory materials for use in the manufacture of glass fiber reinforced plastic fan blades the following points were considered:

II. Test Temperatures

In all considerations where it appeared that temperature affected the strength of the materials, tests were run at approximately the operating temperature of the 8-foot transonic tunnel fan blades (240° F.). The results should give conservative design values for other tunnels for which plastic fan blades are being considered and operating at lower temperatures.

III. Materials

(a) Resins

Three types of resins were considered; phenolic, epoxy, and polyester. Bakelite BV-17085 phenolic resin was considered because it was recommended by the manufacturer for this application. Shell Chemical Corporation's Epon 828 epoxy resin with a "Z" (metaphenalene diamine) hardener was considered since it was recommended by Mr. J. Carey of Shell's Union Technical Service Laboratory for use for fan blades at temperatures up to 250° F. Also, Epon 828 with Chemical Process Company's RP-7 (metaphenalene diamine) hardener was considered because of its heat resistance and low viscosity. Both the unsaturated polyester-styrene and Triallyl cyanurate monomer polyester resins were considered. The Triallyl cyanurate monomer resins such as Naugatuck Chemical Company's Vibrin 135 were considered because of their very high heat resistance but were discarded for fan blade use because they were exceptionally hard and brittle. The unsaturated polyester-styrene resins were considered because of LAL's extensive past experience in model construction with this type material. After preliminary tensile tests, Rohm and Hass Company's Paraplex P-49 was selected as a satisfactory material from this group on which to continue tests. Also, some tests were made using an epoxy resin #1002 with both 181 cloth and Scotch Ply monofiliments.

The phenolic (BV-17085) is suitable for dry lay-up. The Epoxy (Epon 828-"Z") and (Epon 828-"RP-7") is suitable for both dry and wet lay-up and the Polyester (P-49) is suitable for wet lay-up only. The #1002 resin is suitable for dry lay-up only.

(b) Glass cloth

Two types of cloth were considered; 181 (.0085") and 1584 (.023"). Both are 8 harness satin weaves (7 over and 1 under) and have very similar strengths in both the warp and fill directions. All test samples were made with the warp of the cloth parallel to the long dimension. Three types of cloth finishes were considered; Linde Y-1100, Volan A, and Garan. The Linde Y-1100 was selected for laminating with phenolic resins because of the increased strength properties with the finish. Volan A was selected for laminating with the Epoxy and Polyester resins on the recommendations of Shell Chemical and LAL's previous experience with Polyester laminates.

IV. Preparation of Test Specimens

All specimens were prepared and cured in approximately the same manner as would be used in the construction of a fan blade. Specimens are shown by Fig. 1A, 1B, 1C, and 1D.

(a) Phenolic (BV-17085)
Fabric - 1584 (Linde Y-1100 finish)
Number plies - 3 parallel laminated
Resin formulation - 100 parts BV-17085 resin
1-1/2 parts Hexa hardener
Laminating pressure - 90 to 100 psi
Temperature °F. - 325°
Time in press (minutes) - 50 @ 325° F.
Postcure cycle - 20 hours @ 325° F.
Cool in mold

(b) Epoxy (Epon 828-"Z") and (Epon 828-"RP-7")
Fabric - 181 (Volan A finish)
Number plies - 7 parallel laminated
Resin formulation - 100 parts Epon 828
20 parts "Z" hardener or 17 parts "RP-7" hardener
Laminating pressure - pressed to .011"/layer
Temperature °F. - 125°
Time in press - 16 hours
Postcure cycle - 150° F. 1/2 hr.
200 1/2 hr.
250 1/2 hr.
300 1/2 hr. (Some samples with "RP-7" hardener were postcured up to 400° F.)
Cool in oven

(c) Polyester (P-49)
Fabric - 181 (Volan A finish)
Number plies - 7 plies parallel laminated

Resin formulation - 100 parts P-49 (unsaturated Polyester)
10 parts styrene
1/2 parts Luperco A.T.C. paste (50% Benzoyl peroxide and 50% tricresyl phosphate)
1/4 parts accelerator "D" (Celanese Corporation)
Laminating pressure - pressed to .011"/layer
Temperature °F. - 125°
Time in press - 16 hrs.
Postcure cycle - 150° F. for 1/2 hr.
200 1/2 hr.
250 2 hrs.
Cool in oven

V. Short Time Tensile Strength

The specimens were mounted in the tensile machine and held for 30 minutes at temperature and then pulled at a rate of 15,000 psi per minute. A few additional specimens were tested after holding at temperature for five minutes instead of 30 minutes and no appreciable difference in strength resulted. Also, one specimen of each type was tested after holding at temperature for 100 hours. This resulted in a slight increase in strength probably due to more complete curing. At 240° F. the Epoxy (Epon 828-"Z") had a tensile strength of 45,250 psi; the 828 "RP-7" had a tensile strength of 38,800; the Phenolic (BV-17085) had a tensile strength of 37,000 psi; and the Polyester (P-49) had a tensile strength of 43,500 psi. A summary of the results is shown in Fig. 2A. A series of tensile tests were made on Epoxy #1002 resin and scotch ply at room temperature and the results are shown by Fig. 2B.

VI. Long Time or Creep Rupture Tensile Strength

Since tunnel fan blades are required to operate at temperatures up to 250° F. for many hours an investigation to determine the maximum stress which could be carried for 1000 hours was undertaken. Tensile specimens were placed in a heating box, weights were applied through a 10 to 1 lever system to load the specimens to the required stress and the specimen brought to 250° F. by heaters inside the box.

The results showed that over a 1000 hour period, the phenolic, epoxy, and polyester laminates will maintain from 55 to 77% of their short-time tensile strength.

The epoxy laminate (828-"Z") was tested at 76% (35,000 psi) and 66% (30,000 psi) of short time strength and in both cases failed in less than one hour. However, at 55% (25,000 psi) the specimen maintained stress without failure for 1000 hours. The (828-"RP-7") laminate was tested at 90% (35,000 psi) and failed in less than one hour. However at 77% (30,000 psi) the specimen maintained stress without failure for 1000 hours. The polyester laminate maintained stress without failure at 69% (30,000 psi) for 300 hours and both the phenolic and polyester laminates maintained stress without failure for 1000 hours at 25,000 psi or 67% and 57% of their respective short time strengths. The epoxy #1002 resin with scotch ply modified isotropic maintained 62% (35,000 psi) for 1000 hours without failure.

Too few tests were made to determine the exact percentage of short-time strength which can be maintained over 1000 hours but a figure of 60% would appear to be reasonable for design computations.

VII. Short Time Flexural Strength

The specimens were mounted in the flexural machine and held for 15 minutes at 250° F. and stressed approximately at a rate of 3000 psi per minute. At 250° F. the Epoxy resin (Epon 828-"Z") had an average flexural strength of 40,740 psi; the Epon 828-"RP-7" had a flexural strength of 42,100 when post-cured to 300° F. and a flexural strength of 47,100 when post-cured to 400° F., the polyester resin (P-49) had an average flexural strength of 35,100 psi; the Phenolic Resin (BV-17085) with 1584 cloth had an average flexural strength of 42,600 psi; the BV-17085 with 181 cloth had an average flexural strength of 44,500 psi and the scotch ply #1002 modified isotropic had a flexural strength of 59,800 psi. Stress-strain and flexural modulus curves are shown by Fig. 3A. The epoxy resin (Epon 828-"Z") was tested when laminated with a 10% ether solvent and the flexural strength at 250° F. did not exceed 15,000 psi. It was concluded that no solvent should be used for Epoxy laminates to be used at elevated temperatures. Phenolic specimens failed in tension, polyester failed in compression and epoxies failed with a square break at ultimate flexural strength. (This is probably due to the high adhesion strength of the epoxies which prevents delamination at failure.) Results of flexural tests on #1002 scotch ply are shown by Fig. 3B.

VIII. Long Time or Creep Rupture Flexural Strength

Flexural specimens were mounted as two support simple beams loaded by a knife-edge at the center of the span. Specimens were brought to 250° F. and the load applied to bring the specimen to stress. The results showed that over a 1000 hour period at approximately 250° F., the Epoxy (Epon 828-"RP-7") laminates will maintain approximately 83% (35,000 psi) of their short time flexural strength; the Phenolic (BV-17085) laminates will maintain approximately 70% (30,000 psi) of their short time flexural strength; and the Polyester (P-49) laminates will maintain approximately 51% (18,000 psi) of their short time flexural strength without failures.

Epoxy specimens were tested at 40,000, 35,000, and 30,000 psi. The specimen at 40,000 psi failed in 43 hours. The others maintained load for 1000 hours without failure.

Phenolic specimens were tested at 35,000, 30,000, 25,000, and 20,000 psi. The specimen at 35,000 psi broke in less than 1/2 hour. The others maintained load for 1000 hours without failure.

Polyester specimens were tested at 30,000, 25,000, 20,000, 19,000, 18,000, 17,500, and 17,000 psi. The specimen at 30,000 psi broke in less than 1/2 hour. The specimen at 25,000 psi broke in 150 hours. One specimen at 20,000 psi maintained load without failure for 1700 hours; however, a second specimen at 20,000 psi failed in 140 hours and a third specimen failed in 116 hours. The other specimens at 18,000 psi and under maintained load without failure for 1000 hours.

IX. Effect of Internal Heating Due to Alternating Stresses on Strength

Alternating stresses at high frequencies of cycling tend to generate elevated temperatures in plastic laminate with a resultant decrease in strength. The effects of this were observed and evaluated in Forest Products' Report #1823 titled "Fatigue Tests of Glass Fabric Base Laminates Subjected to Axial Loading." The laminate used in these tests was made with 181 cloth and a Polyester resin similar to Paraplex P-49. Results showed that at 20,600 psi alternating stress there was a strength reduction ratio of 1.14 between a cooled and an uncooled specimen. At 9000 psi alternating stress there was no difference in strength between a cooled and an uncooled specimen. At 14,500 psi alternating stress, a 10° rise occurred in the test specimen. This caused a small increase in strength which was attributed to the fact that the test was run with 98% humidity and the heat generated dried the moisture from the specimen.

The tests recorded below were made by Langley's Instrument Research Division on cantilever beams of fiber-glass reinforced with Phenolic (BV-17085), Epoxy (Epon 828-"Z"), and Polyester (P-49) and vibrated at 30 cps and at stress levels from 7,000 to 12,000 psi at the root. No significant temperature changes were noted. The results are:

Material	Time	Frequency	Stress	Temperature Rise
Phenolic (BV-17085)	20 min	25 cps	12,000 psi	1° F.
Epoxy (Epon 828"Z")	20 min	30 cps	7,000 psi	1-1/2° F.
Polyester (P-49)	30 min	30 cps	10,000 psi	1-1/2° F.

An approximate temperature rise for wind tunnel fan blades due to vibratory stresses can be calculated by making the following assumptions:

(a) A uniform cantilever vibrating in the first mode at the first resonance frequency.
(b) A linear variation of internal stress.
(c) No heat loss to the surrounding medium.
(d) The entire cantilever is heated uniformly.

The temperature rise per unit time is:

$$T = \frac{Z_1^2}{(778)(12)(6)} \frac{\zeta}{L^2\sqrt{E}} \left[\frac{I}{\rho A}\right]^{3/2} \frac{S_r^2}{S_p}$$

where

T = temperature rise, °F/sec.
Z_1 = characteristic root of cantilever in the first mode, Z_1 = 1.87 for simple cantilever
ζ = critical damping ratio
L = length of cantilever, inches
I = moment of inertia, in. 4
E = young's modulus, lbs/sq.in.
ρ = density, slugs/cu.in.
A = cross sectional area
S_r = stress at the root surface, lbs/sq.in.
S_p = specific heat, BTU/lb/°F.

X. Effect of Notches on Strength

Results obtained from tests by Forest Products and summarized in report #1839 dated June 1953, indicate that notched specimens will maintain approximately 80% of the load in tension that an unnotched specimen will maintain. This ratio applies to both long and short periods of time under load. Tests were made with 1/2 inch wide specimens with a 1/8 inch hole at the center of the section. Calculations indicate that the stress at the edge of the hole is about 3-1/2 times the average stress (Forest Products Report #1510).

Compressive tests indicate that plastic laminates show little notch sensitivity under compressive stresses.

Fatigue strength was lowered about 20% for the notched specimens listed above as compared to unnotched specimens of the same size.

A series of tensile tests were made at Langley to determine the effect of strength of the blade attachment notches in the butt of wind tunnel fan blades. Three types of notches (square end, round end, and triangular end) (see Fig. 1D) were tested in tension. Results showed no appreciable difference in strength for notches with different shaped ends. The notch specimens were from 72.3% to 76% as strong as unnotched specimens. Failure in all cases occurred at any change in direction of the slot from a direction parallel to the tensile load (and parallel to the cloth weave).

For design of wind tunnel fan blades, a figure of 70% of the short time ultimate tensile strength would appear reasonable to allow for the notch effect of the blade attachment slots.

Test Results at 77° F.

Epoxy (Epon 828"Z") Specimens		Polyester (P-49) Specimens	
Un-notched Specimens		**Un-notched Specimens**	
Specimen No.	Ult. Tensile Stress (PSI)	Specimen No.	Ult. Tensile Stress (PSI)
A1	49,200	A1	44,200
A2	48,000	A2	43,000
Average =	48,600	Average =	43,600
Square End Notch		**Square End Notch**	
B1	37,400	B1	29,000
B2	35,700	B2	32,500
B3	35,700	B3	32,500
Average =	36,266	Average =	31,333
% of un-notched strength =	74.6	% of un-notched strength =	71.8

Round End Notch		Round End Notch	
C1	37,000	C1	31,900
C2	34,500	C2	31,600
C3	35,200	C3	32,500
Average =	35,566	Average =	32,000
% of un-notched strength = 73.3		% of un-notched strength = 73.4	

Triangular End Notch		Triangular End Notch	
D1	37,000	D1	28,800
D2	37,000	D2	36,000
D3	36,700	D3	29,700
Average =	36,900	Average =	31,500
% of un-notched strength = 76		% of un-notched strength = 72.3	

XI. Effect of Molding Pressure and Resin Content on Strength

Results of a series of tests on effect of molding pressure and resin content on strength were reported in National Bureau of Standards Report #4085 dated June 1955. The tests were made using a polyester resin similar to Paraplex P-49 reinforced with 181 glass cloth.

Their conclusions were that the type of mold and pressure do not appreciably affect laminate strength, but that strength is primarily a function of resin content. In other words, two laminates with the same resin content will have similar physical properties no matter what pressure was used in molding or what type mold is used. Also molding pressure has no appreciable affect on flexural, tensile, or compressive properties or resin content or voids content of panels fabricated in a closed mold. Laminates fabricated in an open mold show an increase in flexural and tensile properties as molding pressure is increased up to 10 psi but shows no appreciable increase above this pressure. The compressive strength decreases with increased molding pressure. The strength properties of both open and closed mold panels are similar for similar resin contents.

The open mold did not restrain the resin at the edges of the laminate from flowing outward under pressure; whereas, the closed mold restrained resin flow at the edges of the laminate. The resin content of closed mold panels did not vary appreciably with increase in pressure; but the free-edge or open mold panels decreased in resin content with an increase in molding pressure. Results are as follows:

Mold Press (psi)	Resin Content (%)	Average Thickness Per Layer of 181 Cloth	Voids Content (%)	Flexural Ultimate (psi)	Tensile Ultimate (psi)	Ultimate Tens. Load per Layer of Cloth (pounds)	Compress. Ultimate (psi)
Open Mold							
1	41.9	.0118	.5	58,400	41,900	495	43,400
10	28.4	.0086	.6	68,000	54,600	470	35,400
100	24.5	.008	1.2	66,100	58,000	464	34,700

Closed Mold							
10	38.8	.011	.4	65,600	46,200	497	44,500
100	39.4	.0112	.7	65,100	45,100	505	39,500
500	39.1	.011	.4	65,900	45,500	500	44,300

From the above table, it is observed that the tensile load per layer of cloth is relatively independent of resin content, except below 30% resin content there is a reduction in strength because the adhesion between layers of glass is insufficient to develop the full strength of the laminate.

Optimum resin content for wind tunnel fan blades appears to be from 34% to 38%.

Resin content can be calculated from the thickness of a laminate as follows:

$$\frac{\text{Weight Resin}}{\text{Weight Glass Cloth} + \text{Weight Resin}} = \text{\% Resin content by weight}$$

$$\frac{(V_T - V_G)(S.G.)(.0361\#/\text{cu.in.})}{(W_G)+(V_T - V_G)(.0361)(S.G.)} = \text{\% Resin content by weight}$$

V_T = Volume of laminate per sq.yd. per layer fabric = (t) (1296) = $\frac{\text{cu.in.}}{\text{sq.yd.}}$

t = $\frac{\text{Total thickness of laminate}}{\text{Number of layers of cloth}}$

S.G. = Specific gravity of resin

W_G = Weight of glass per layer (#/sq.yd.)

V_G = Volume of glass cloth per sq.yd. per layer $\frac{\text{cu.in.}}{\text{sq.yd.}}$

$V_G = (10.473)(W_G)\ \frac{\text{cu.in.}}{\text{sq.yd.}}$

Calculated resin content for laminates with 181, 143, and 1584 cloth is shown in Fig. 4.

Effect of resin content on tensile ultimate load is shown in Fig. 5. This curve is plotted from data from Forest Products Report #1814 and represents the averages of 8 specimens at each resin content. Specimens were Polyester resin reinforced with 181 cloth. The optimum resin content for laminates in tension appears to be 38%.

Since no volatiles are given off in molding the Epoxy resins, pressures above 10 psi will satisfactorily produce void free laminates of high strength and the same strength trends as shown above for the Polyester resins will apply to the Epoxy resins.

For molding with Phenolic Resins, since the impregnated cloth contains a small amount of residual solvents and also since water of condensation is given off during curing, it is difficult to produce void free parts of high physical properties without high pressures. Therefore, higher pressures (90 to 100 psi) are recommended when using Phenolic (BV-17085) resins in wind tunnel fan blades than when using Polyester or Epoxy resins.

XII. Effect on Strength of Defects (Wrinkles)

Tests reported by Forest Products Report #1814 dated June 1950 on effect of wrinkles in Polyester laminates reinforced with 181 glass cloth show a definite reduction in both tensile and compressive strength in laminates with wrinkles.

Panels were fabricated with wrinkles of two different depths (.015 and .030 inches). Wires, .015 and .030 inches in diameter, were layed inside the mold surface to produce a 12% and a 23% deep wrinkle in one surface of the laminate perpendicular to the direction of load.

Specimens with 12% deep wrinkles were 79% as strong in tension and 98% as strong in compression as unwrinkled specimens. Specimens with 23% deep wrinkles were 70% as strong in tension and 74% as strong in compression as unwrinkled specimens.

No tests of long time creep rupture effects on wrinkles specimens were made, but comparing a wrinkle to a notch it can be concluded that the percentage reduction in strength based on short time tests will also apply to the long time creep rupture strength. In other words, P-49, 828-"Z", 828-"RP-7", and BV-17085 laminates with a 23% deep wrinkle could be expected to maintain (.70) (25,000) = 17,500 psi in tension for 1000 hours at 250° F. without failure.

XIII. Effect of Sewing Glass - Cloth on Strength

Specimens were fabricated from 7 layers of 181 glass cloth and P-49 resin. The 7 layers of cloth were machine sewn with a 1/8 inch length of stitch before saturating with resin, using #50 thread and a #14 needle. Four specimens were not sewn and were used as control specimens, four were sewn crosswise (perpendicular to the direction of load) with seams spaced 1/4 inch on centers, and four were lengthwise sewn parallel to load. Average tensile strengths are as follows: control - 49,000 psi; cross sewn - 46,000 psi; lengthwise sewn - 49,000 psi.

It was concluded from these tests that pre-sewing of the cloth before laminating has no appreciable affect on the tensile strength. All tests were run at room temperature by NACA Structures Laboratory.

XIV. Interlaminar Shear Strength

The results reported from the shear strength of Polyester laminates and Epoxy laminates along a plane parallel to the layers of cloth by ANC-17, indicates that the Epoxy laminates have higher shear strength (6,800 psi) than the Polyester laminates (4,800 psi).

Tests made at Langley at room temperature (using samples as shown by Fig. 1C) showed average interlaminer shear strengths as follows:

Polyester (P-49) - 2340 psi (181 cloth, Volan A finish)
Epoxy (Epon 828-"Z") - 2750 psi (181 cloth, Volan A finish)
Phenolic (BV-17085) - 2350 psi (181 cloth, Linde "Y" 1100 finish)

These values are considerably less than those given by ANC-17. Since these specimens were pulled in tension, notch sensitivity probably caused some reduction in apparent strength. Any future tests for interlaminar shear should be made in compression thus minimizing the notch effect. However, previous tests on P-49 made in compression gave an interlaminar shear strength of 2400 psi which is in good agreement with the present test results. Therefore, it appears that no higher values than those listed should be used for design.

The peel strength of laminates made with Epon 828-"Z" and 828-"RP-7" is much superior to P-49 and BV-17085. Epon 828-"Z" and 828-"RP-7" laminates are practically impossible to peel; whereas, both P-49 and BV-17085 laminates peel readily and have approximately equal peel strengths.

XV. Flexural Creep Properties

Creep deflections were measured over a 1000 hour period by the use of dial gages on the creep rupture flexural specimens described in paragraph VIII. Calculations for an Apparent Flexural Modulus of Elasticity were made from these deflection readings for each specimen tested. The creep or modulus curves are shown in Fig. 6. The rate of creep at 1000 hours was negligable for most of the specimens that maintained load without failure.

From the measured deflection and with a given stress the Flexural Modulus can be found by using the Nomograph shown in Fig. 7.

XVI. Cost of Materials As Of June 20, 1956

(a) Wet lay-up process

1. Polyester (P-49)

181 cloth	$1.10/sq.yd.
Resin (40¢/#)	.08/sq.yd.
	$1.18/sq.yd. (cloth & resin)

2. Epoxy (Epon 828)

181 cloth	$1.10/sq.yd.
Resin ($1/#)	.19/sq.yd.
	$1.29/sq.yd. (cloth & resin)

(b) Pre-preg lay-up process

1. Phenolic (BV-17085

Impregnated 181 cloth/sq.yd.	$2/sq.yd. (cloth & resin)

2. Epoxy (#1002)

Impregnated 181 cloth/sq.yd.	$3.50/sq.yd. (cloth & resin)

XVII. Effect of Freon 12 Atmosphere on Blade Materials

Since fan blades for the converted 19-foot tunnel will operate in a Freon-12 atmosphere at 155° F., the effects of Freon-12 at 155° F. on glass cloth laminates made with Epon 828-"RP-7", Epon 828-"Z", P-49, BV-17085, and Scotchply #1002 were investigated.

Specimens of the above materials were mounted as simple beams inside a 9-inch diameter steel cylinder. Each specimen was loaded in bending to 15,000 psi by a lead weight suspended from a knife edge at the center of the specimen. Also a block of "Strux" and an adhesive joint made with "Epon 8" were placed in the cylinder. The cylinder was capped and then was evacuated to 1/2-inch of mercury and Freon-12 introduced until the internal pressure reached 15 psi. The temperature of the Freon was raised to 155° F. by heating coils inside the cylinder.

All the specimens showed no damage at the end of 1000 hours.

XVIII. Fatigue Strength of Laminates Subjected to Axial Loading

Fiberglass laminates are essentially "dead" materials; that is, they will damp out vibrations in a few cycles as compared to a resonant material such as steel or aluminum which will sustain a vibration for many cycles. This property of damping capacity is measured by the Logarithmic Decrement of the material which is the natural logarithm of the ratio of the amplitudes of two successive vibrations of constant frequency after the initial stimulus has been removed. The logarithmic decrement for one sample Polyester blade in the downstream fan of the 8-foot transonic tunnel is 0.605 with the blade clamped at the socket and the logarithmic decrement for the wooden blade adjacent to the plastic blade is 0.12. This indicates that even with operation of the plastic blades at a resonent condition (frequency ratio of 1) no large amplitudes or vibratory stresses should be built up.

A series of tests were made on Phenolic, Polyester, and Epoxy laminates to determine the endurance limit at 250° F. Specimens as shown by Fig. 1B were stressed in tension to a mean stress of 10,000 psi and an alternating stress superimposed on the mean stress. These specimens were run under these conditions to failure and the cycles recorded. The temperature of the specimens was maintained at 240° F. by heat lamps on both sides of the specimen which were controlled from thermocouples located adjacent to the specimen.

Summary of Fatigue Tests

Temperature - 240° plus or minus 5°
Shape of Specimen - hour glass - min cross section 1" x .088"
Mean Stress all Tests - 10,000 psi
Load applied at 1800 c.p.m.

Material	Specimen No.	Alternating Stress (psi)	Life (cycles)	Comments
Phenolic (BV-17085)	1	2,000	42,558,000	Did not fail at this stress.
	1	4,000	1,135,000	Same specimen with stress raised.
	2	4,000	2,977,000	
	3	3,000	1,615,000 to 9,921,000	Machine did not stop when specimen failed.
Polyester (P-49)	1	2,000	36,705,000	Did not fail at this stress.
	1	4,000	89,000	Same specimen with stress raised.
	2	4,000	453,000 to 7,332,000	Machine did not stop when specimen failed.
	3	4,000	17,986,000	
	4	3,000		
	5	9,000	6,000	
	6	6,000	39,000	
Epoxy (828-"Z")	1	4,000	7,362,000	
	2	3,000	151,000,000	Did not fail
	3	9,000	14,000	
	4	6,000	115,000	

In view of the above results and considering the fact that the mean stress in wind tunnel fan blades is in the order of 4000 psi and since the material shows excellent damping leading to low vibratory stresses, it was concluded that fatigue was not a significant factor as long as the mean stress and alternating stress each do not exceed 4000 psi. An S-N curve for Polyester (P-49) and Epoxy (Epon 828-"Z") is shown by Fig. 8. The S-N curve shown on Fig. 8 for a mean stress of 4000 psi can be used as a design guide for wind tunnel fan blades to prevent fatigue failures.

XIX. Summary of Results

In conclusion it appears that fiberglass reinforced plastic laminates made with Epoxy (Epon 828 with Metaphenalene Diamine hardener), Phenolic (BV-17085), and Polyester (P-49) can all be used to make satisfactory wind tunnel fan blades operating at temperatures up to 250° F. The following factors are involved in arriving at a safe 1000 hour operating limit for these materials: notch factor, temperature factor, creep rupture factor, and defect factor.

The allowable design stress in tension at 250° F. for 1000 hours life without failure equals: (notch factor) x (temperature factor) x (creep rupture factor) x (defect factor based on 12% deep wrinkle) x (short time ultimate tensile strength at 77° F.)

For Polyester (P-49) = (.70) (96.5) (.57) (.79) (45,000) = 13,700 psi
For Epoxy (828-"RP-7") = (.70) (.85) (.77) (.79) (45,000) = 16,300 psi
For Phenolic (BV-17085) = (.70) (.88) (.67) (.79) (42,000) = 13,700 psi

In the writers opinion, the Epoxy material is superior to the others tested for use in the manufacture of wind tunnel fan blades. The Epoxy materials give the highest allowable design stress, absorb less moisture, and have superior peel and interlaminar shear strength.

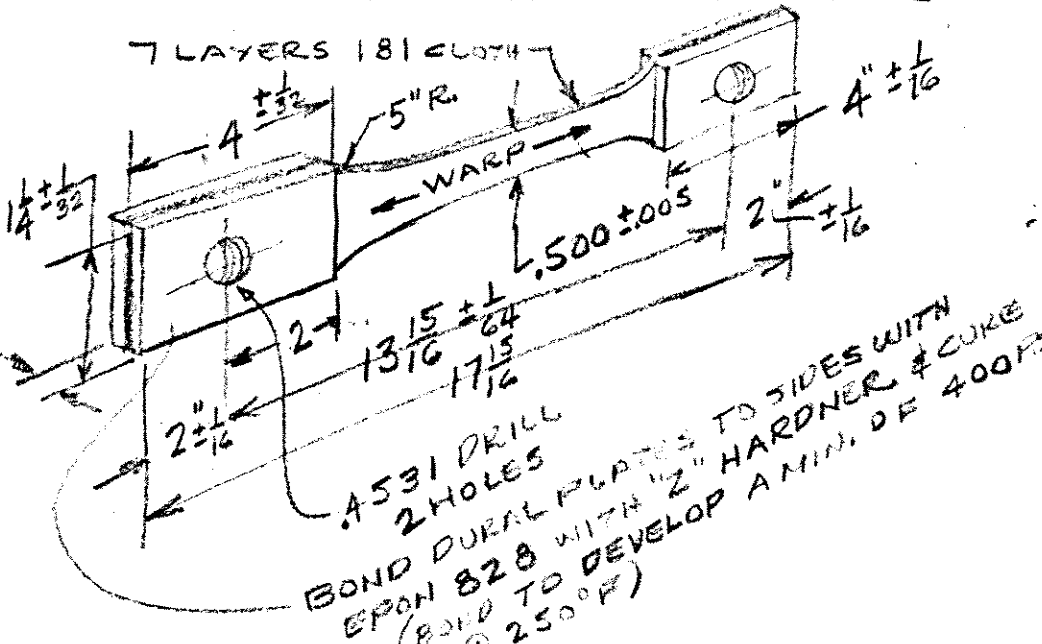
E. C. Kilgore

SUMMARY OF TEST RESULTS

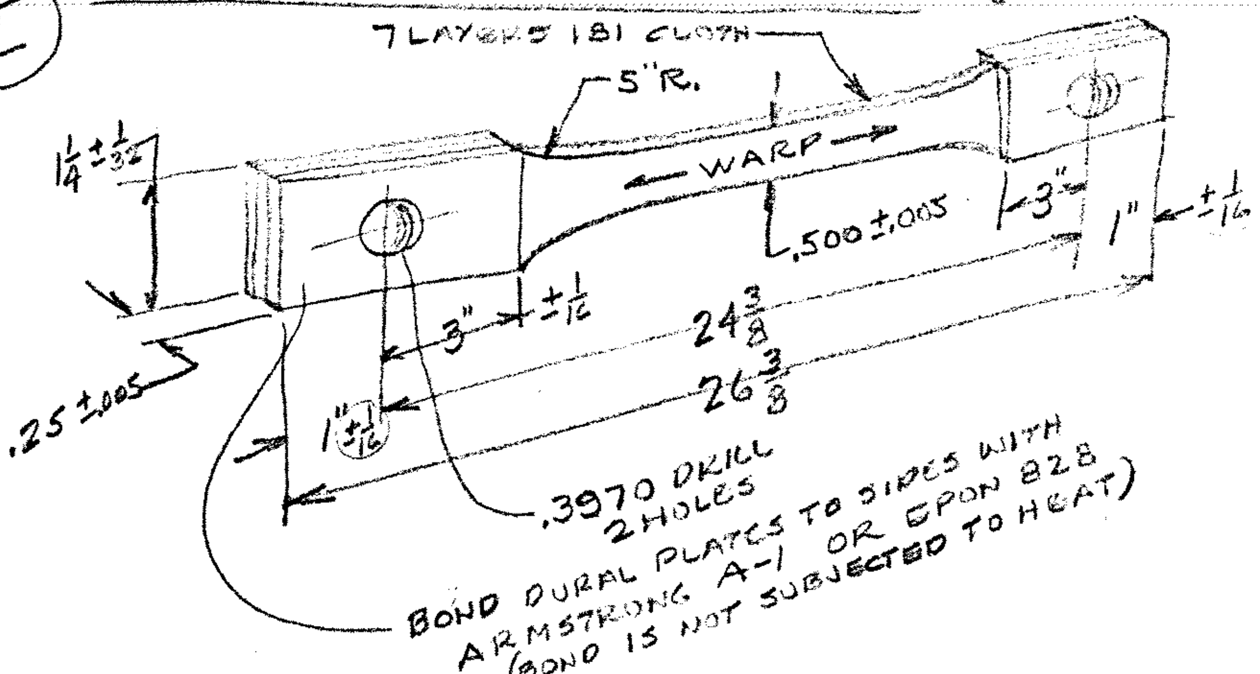
Type Resin			Epoxy	Phenolic	Polyester
Resin #			828 (Metaphen-alene Diamine)	BV-17085	P-49
Cloth # & Finish			#181 Volan A	#1584 Y-1100	#181 Volan A
Tension	Short Time Ultimate (psi)	77°F	52,000	42,000	45,000
		240°F	45,250	37,000	43,500
	1000 Hour Ultimate (psi)	250°F	25,000	25,000	25,000
Flexure	Short Time Ultimate (psi)	250°F	40,740	42,600	35,100
	1000 Hour Ultimate (psi)	250°F	35,000	30,000	18,000
	Initial Modulus of Elasticity (1000 psi)	250°F	2,120	2,440	2,460
Interlaminar Shear (psi)		77°F	2,750	2,350	2,340
Axial Fatigue	Endurance Limit @ 250°F in Cycles 10,000 psi Mean Stress 3000 psi Alternating Stress		151.0×10^6 (did not fail)	1.615×10^6 to 9.921×10^6	56.75×10^6
	10,000 psi Mean Stress 4000 psi Alternating Stress		7.362×10^6	2.977×10^6	17.986×10^6
	10,000 psi Mean Stress 6000 psi Alternating Stress		1.15×10^5	- - -	3.9×10^4
	10,000 psi Mean Stress 9000 psi Alternating Stress		1.4×10^4	- - -	6×10^3

BY OK DATE SUBJECT TEST SPECIMENS SHEET NO. OF
CHKD. BY DATE JOB NO.

I) LONG TIME TENSILE CREEP SPECIMENS (HEAT BOX IN 8' TUNNEL)



II) SHORT TIME TENSILE SPECIMENS (STRUCTURES LAB)



III) SHORT & LONG TIME FLEX. SPECIMENS (WEST SHEET METAL)

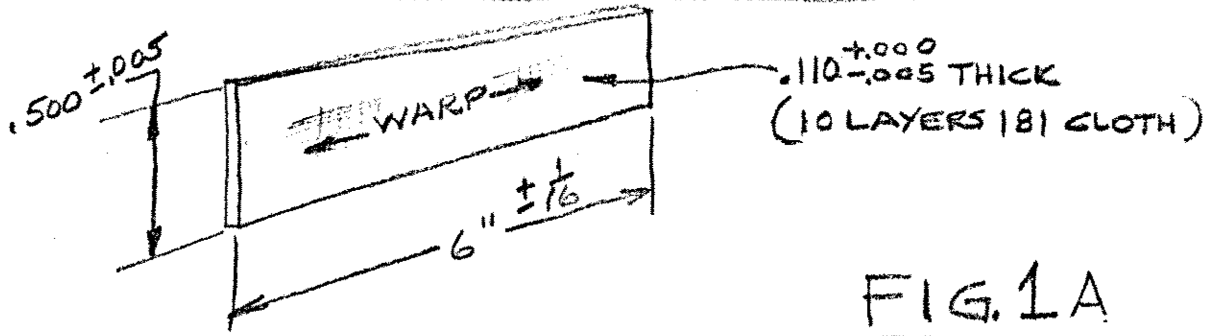


FIG. 1A

BY .... DATE .... SUBJECT FATIGUE SPECIMAN SHEET NO. .... OF ....

CHKD. BY .... DATE .... JOB NO. ....

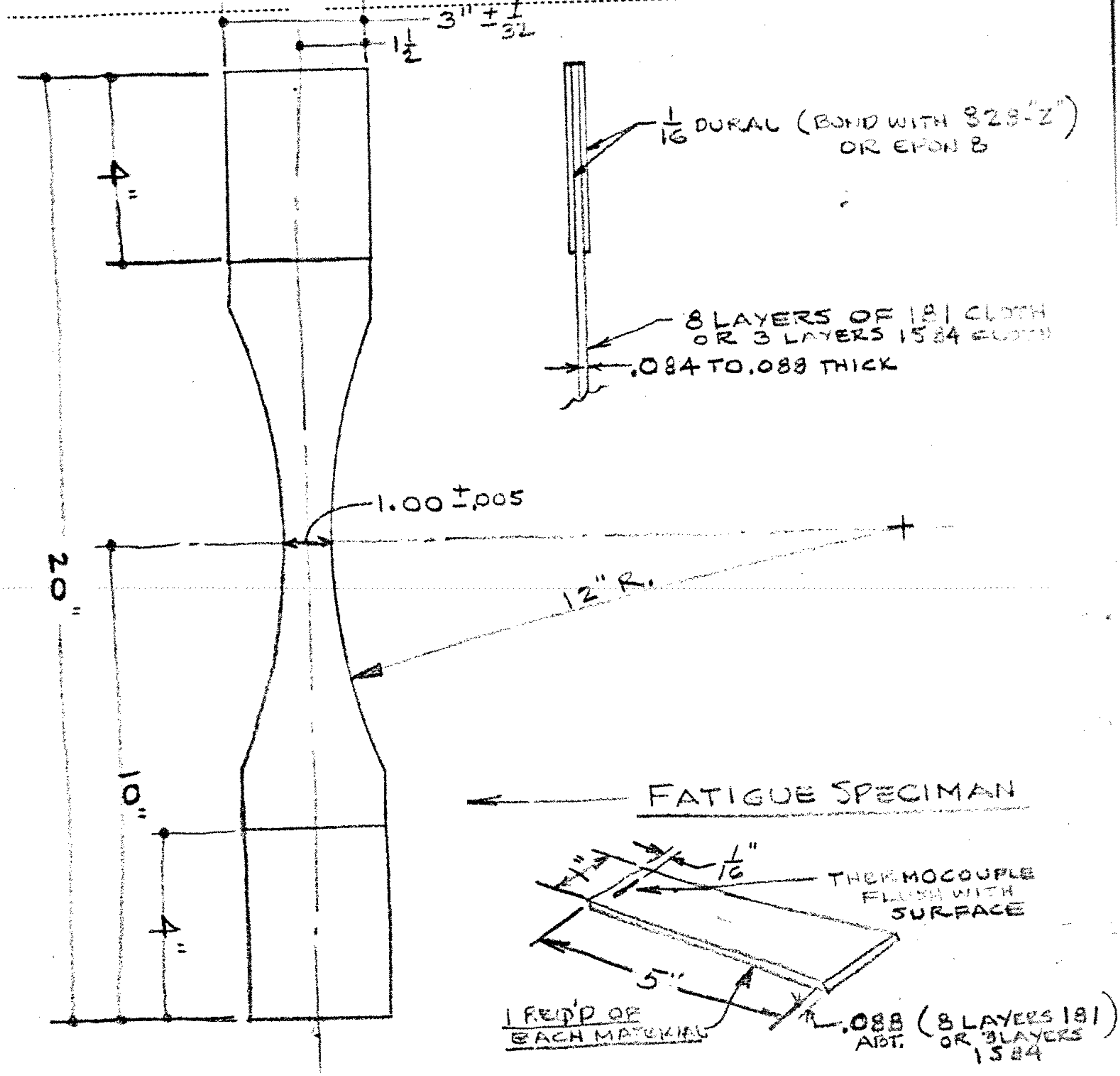


FIG. 1B

SUBJECT INTERLAMINAR SHEAR SPECIMANS
SHEET NO. .... OF ....
JOB NO. ....
BY .... DATE ....
CHKD. BY .... DATE ....

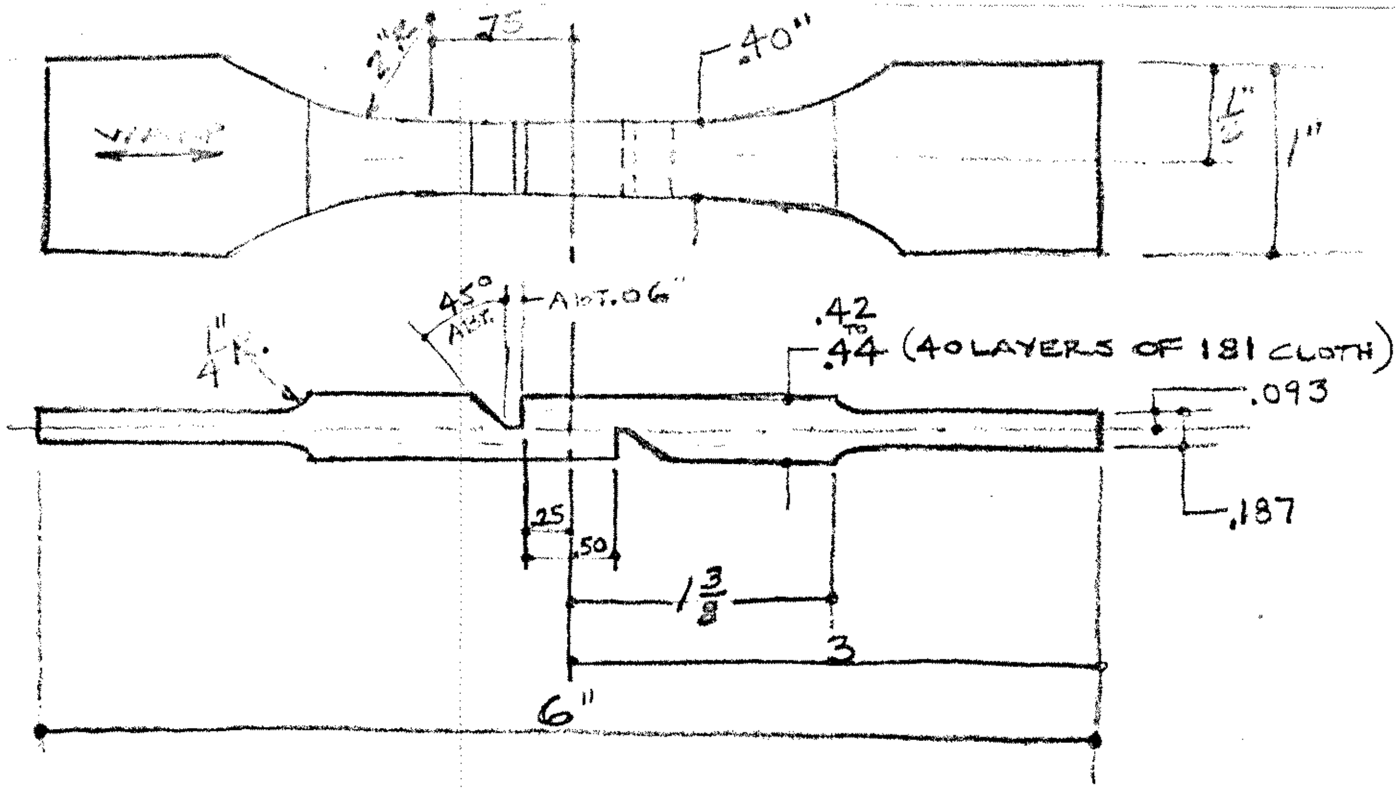


FIG. 1C

INTERLAMINAR SHEAR SPECIMANS

3 REQ'D 828 "Z" HARDNER
3 REQ'D P-49
3 REQ'D BV-17085

SHEET NO. .... OF ....
JOB NO. ....
SUBJECT NOTCH SPECIMENS
BY .... DATE ....
CHKD. BY .... DATE ....

NOTCH SPECIMENS

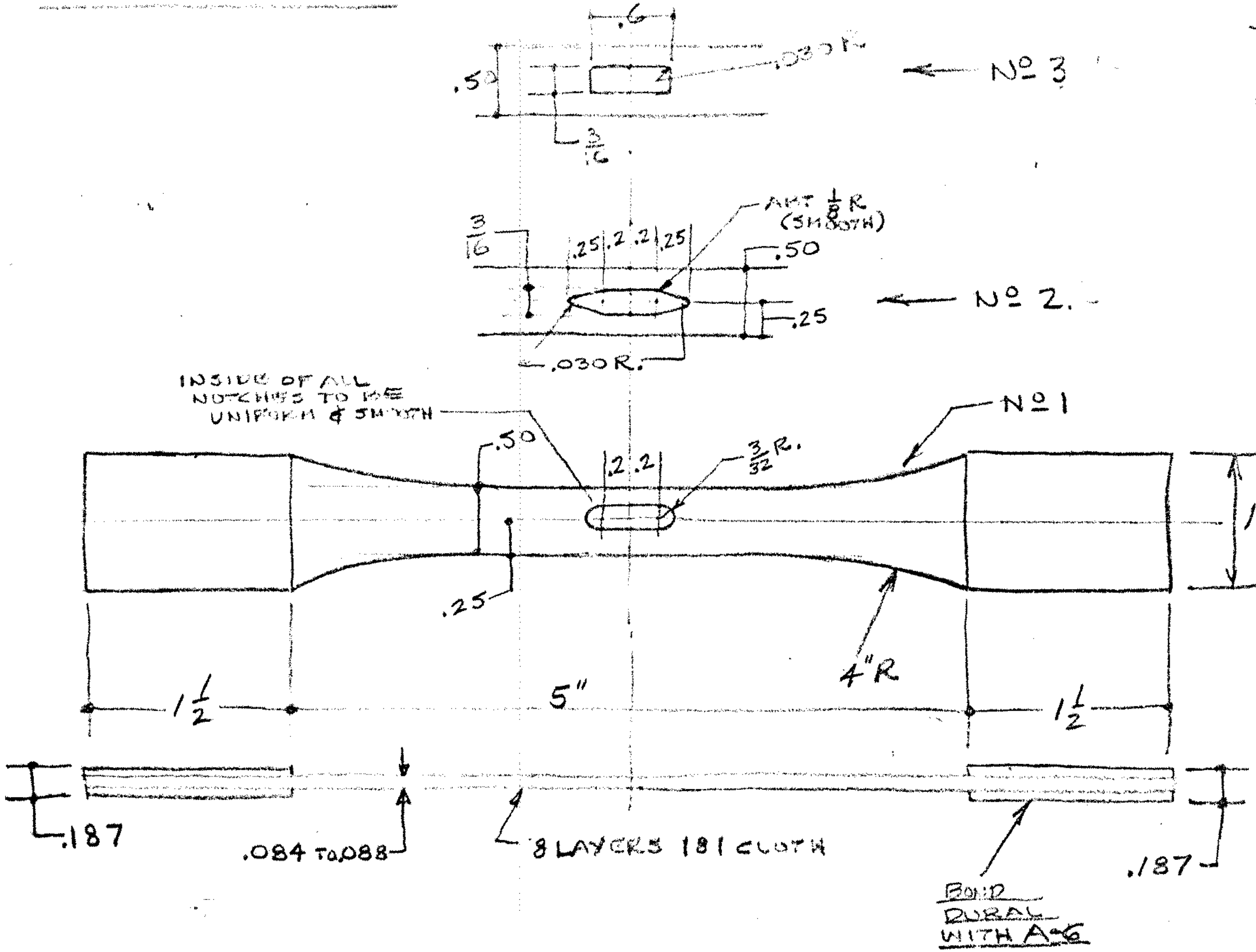


FIG 1D

BY KILGORE DATE 1/10/56 CHKD. BY ...... DATE ......

SUBJECT FIBERGLAS - REINFORCED PLASTIC SHORT TIME TENSILE [illegible]

SHEET NO. ...... OF ...... JOB NO. ......

① RESULTS OF SHORT TIME TENSILE TESTS BY NACA STRUCTURES LAB 1/10/56

② SPECIMANS WERE .500 WIDE X .080 THICK WITH 7 LAYERS OF 181 CLOTH EXCEPT AS NOTED

③ RESIN CONTENT WAS ABT. 38% EXCEPT AS NOTED

④ SPECIMANS WERE HEATED TO TEMP. & HELD FOR 30 MIN. & PULLED @ 15,000 PSI/MIN.

⑤ CLOTH FINISH IS AS NOTED ON EACH CURVE

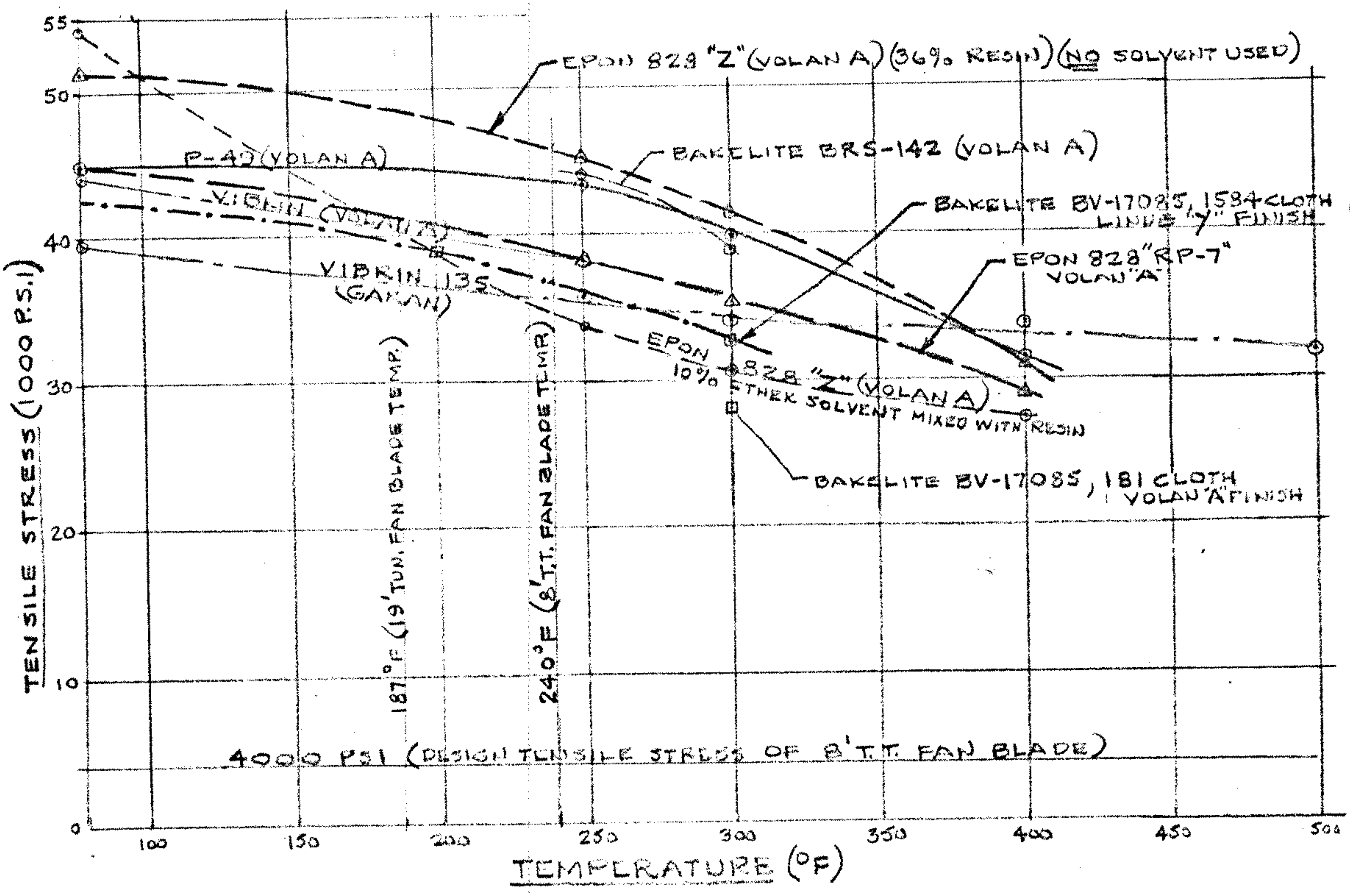
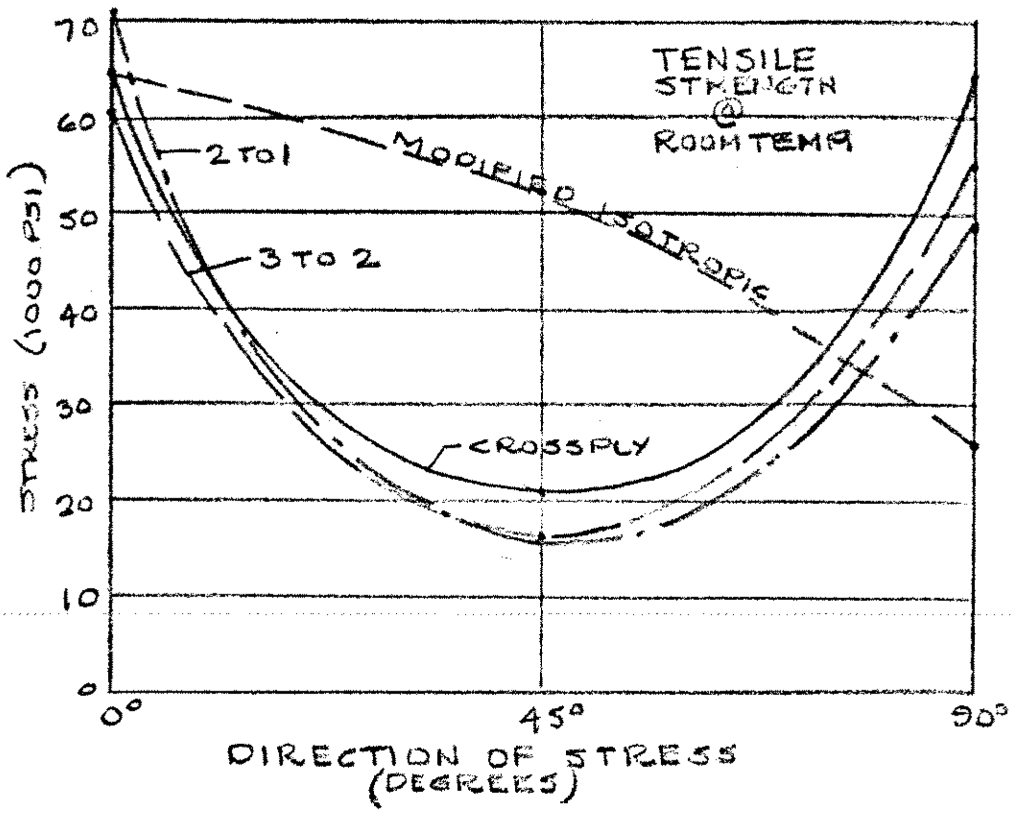


FIG. 2A

BY.................DATE.......... SUBJECT TENSILE STRENGTH OF SCOTCH PLY #1002 SHEET NO. ....OF.......

CHKD. BY........ DATE.......... JOB NO.....................

SPECIMANS TESTED AT ROOM TEMPERATURE IN TENSION, LOAD AT .25"/MIN



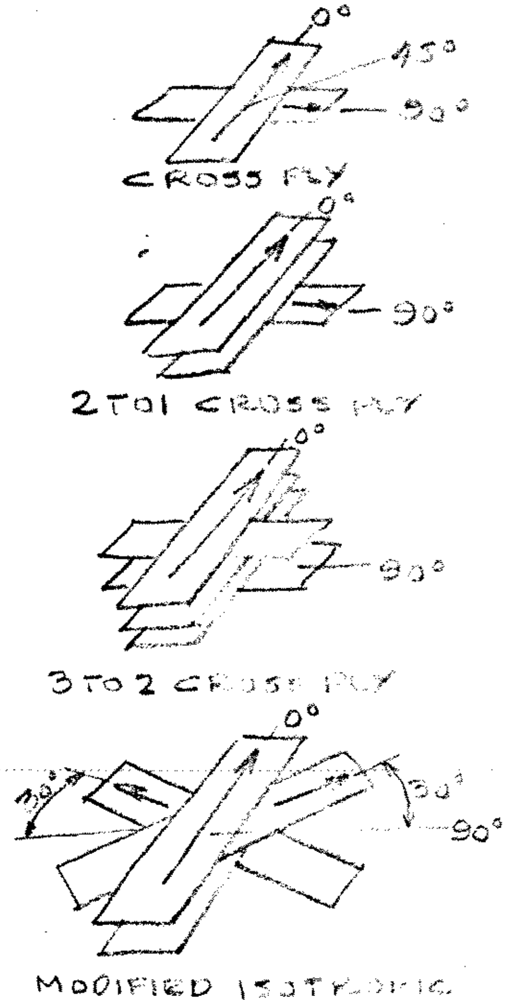


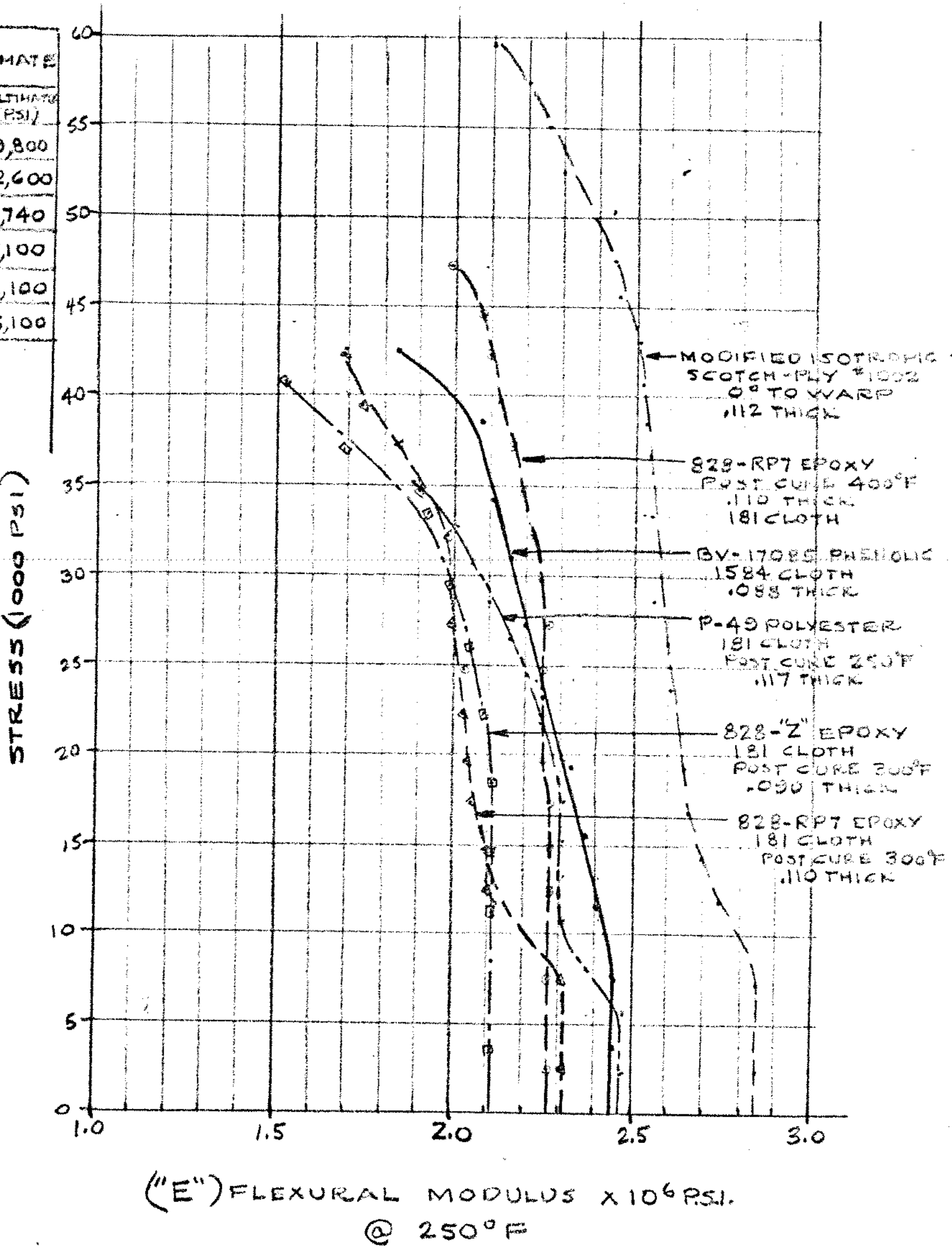
FIG. 2B

BY CK DATE 6/6/56 SUBJECT FLEXURAL TESTS @ 250°F SHEET NO. ...... OF ......

CHKD. BY ...... DATE ...... JOB NO. ......

SHORT TIME FLEXURAL ULTIMATE @ 250°F

ESIN	CLOTH #	POST CURE °F	THICK "	ULTIMATE (PSI)
TCH PLY 1002	MOD. ISO.	300	.112	59,800
-17085	1584	325	.088	42,600
8-"Z"	181	300	.090	40,740
8-"RP7"	181	400	.110	47,100
8-"RP7"	181	300	.110	42,100
-49	181	250	.117	35,100



$$"E" = \frac{WL^3}{48 I \delta} = \frac{(8)(\text{STRESS})}{3 \delta h}$$

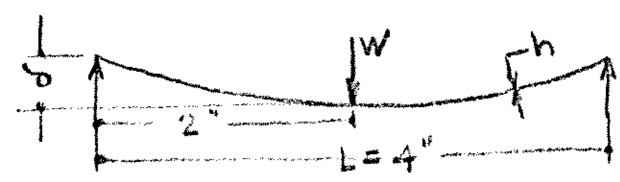
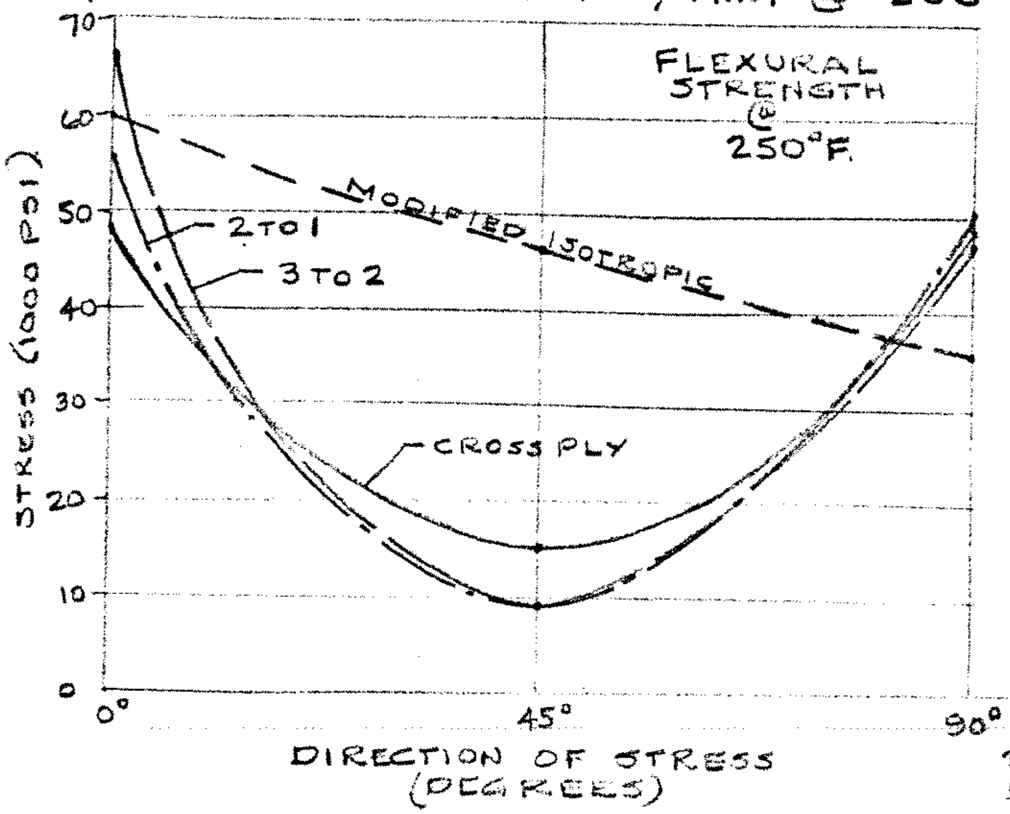


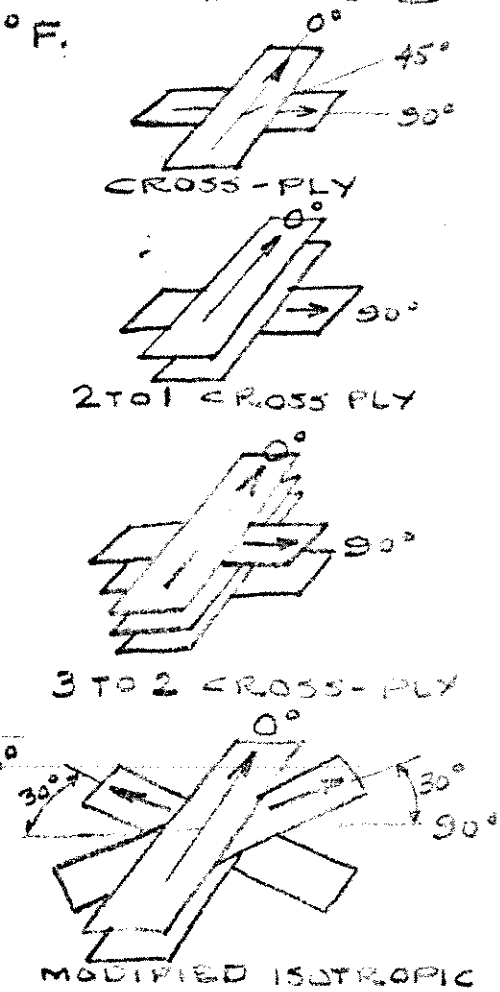
FIG. 3A

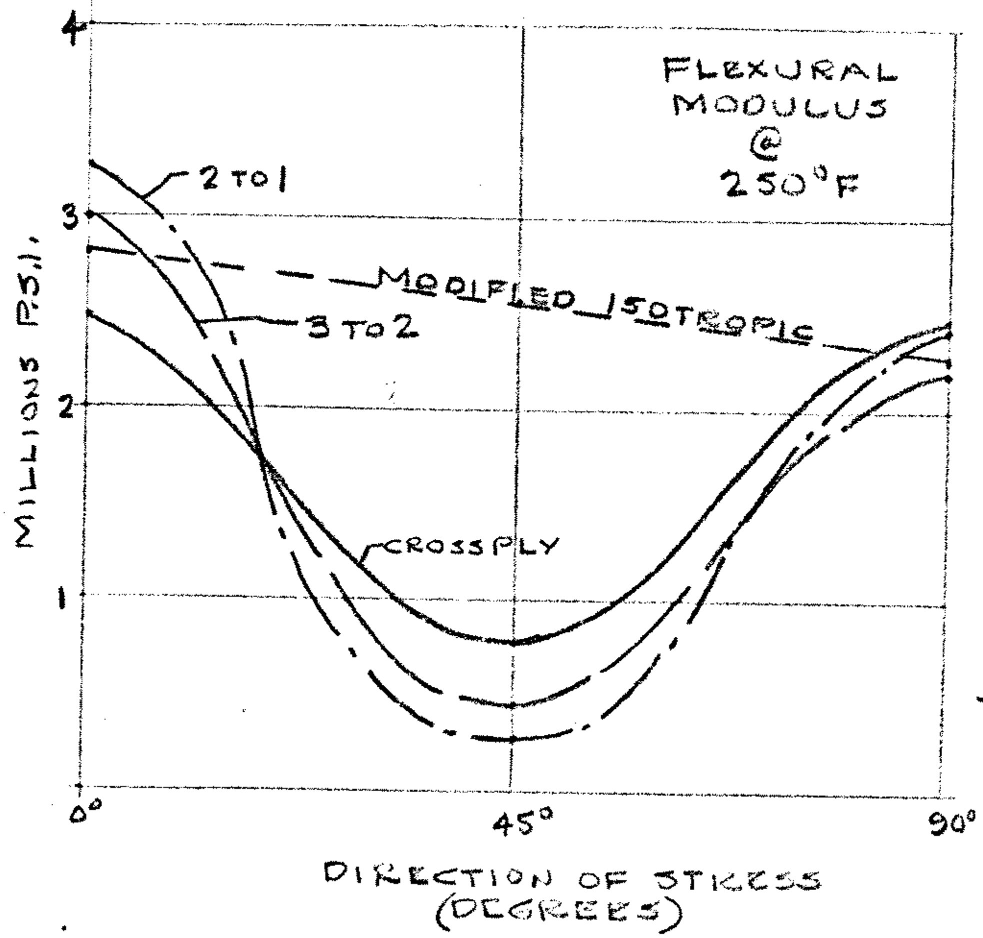
BY DK DATE 5/7/56 SUBJECT STRENGTH OF SCOTCH-PLY #1002

CHKD. BY .... DATE .... SHEET NO. .... OF .... JOB NO. ....

SPECIMANS HELD FOR 15 MIN. AT TEMPERATURE & THEN LOADED AT 10#/MIN. @ 250°F.







FLEXURAL STRENGTH @ 250°F (PSI)

MATERIAL	0° & 90°		45°
P-49	35,100		20,000
BV-17085	42,600		22,000
828-Z	40,740		22,000
SCOTCHPLY CROSSPLY	48,477		15,306
SCOTCHPLY MODIFIED ISOTROPIC	0° 60,000	90° 35,714	46,556

FIG. 3B

SHEET NO. .... OF ....
JOB NO. ....

SUBJECT RESIN CONTENT

BY G.K. DATE 8/4/56
CHKD. BY .... DATE ....

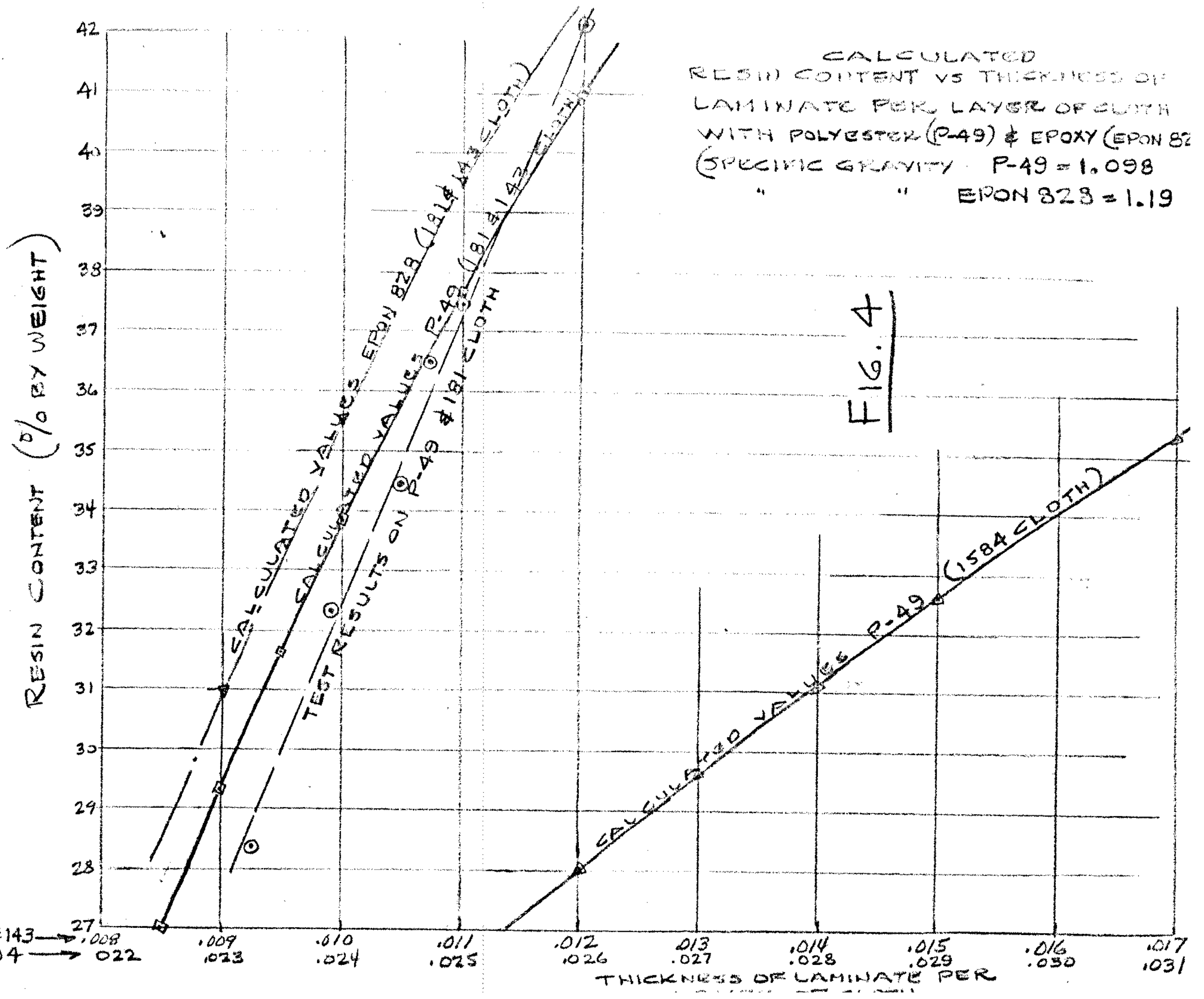


FIG. 4

BY .... DATE .... SUBJECT .... SHEET NO. .... OF ....
CHKD. BY .... DATE .... JOB NO. ....

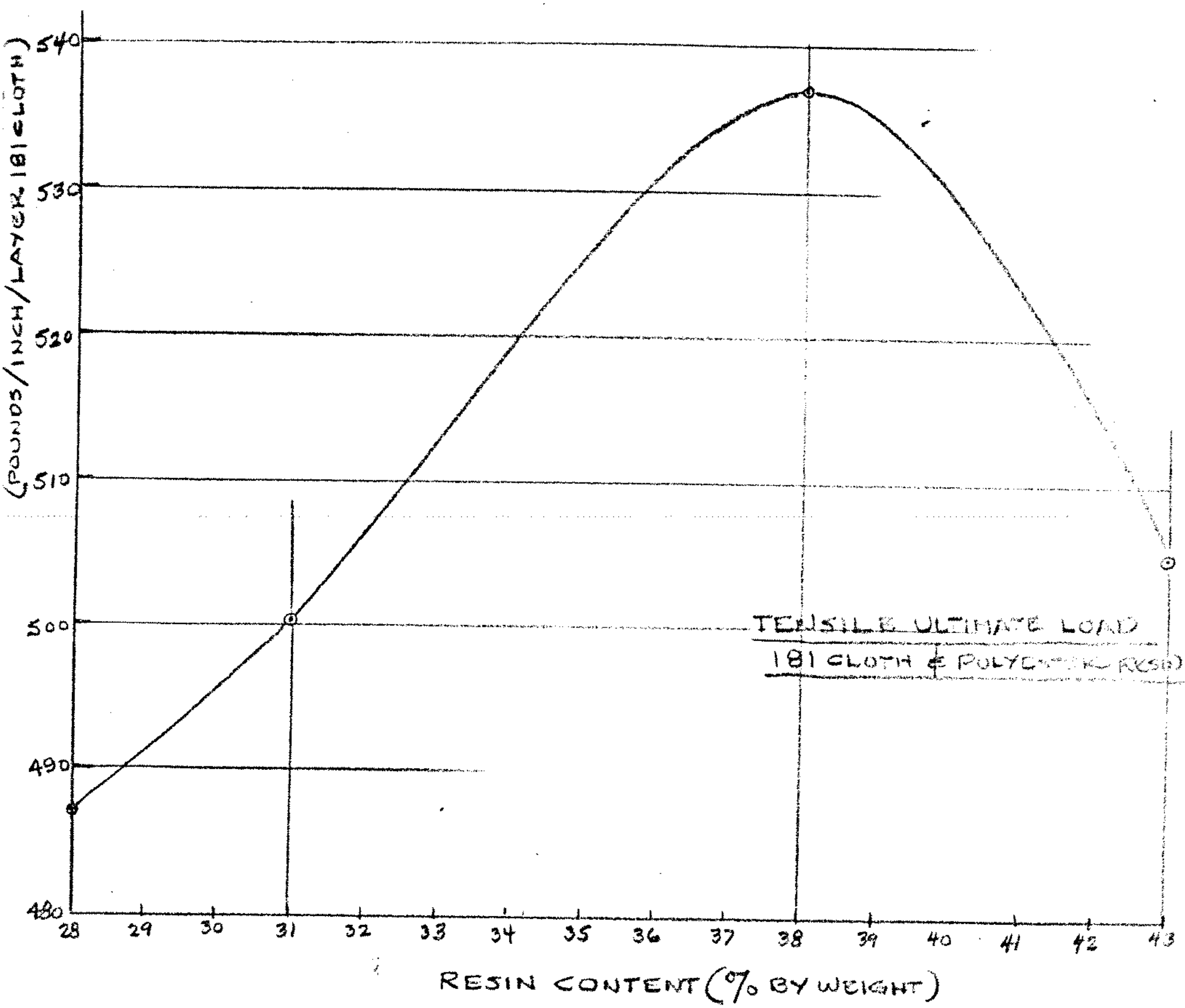


FIG. 5

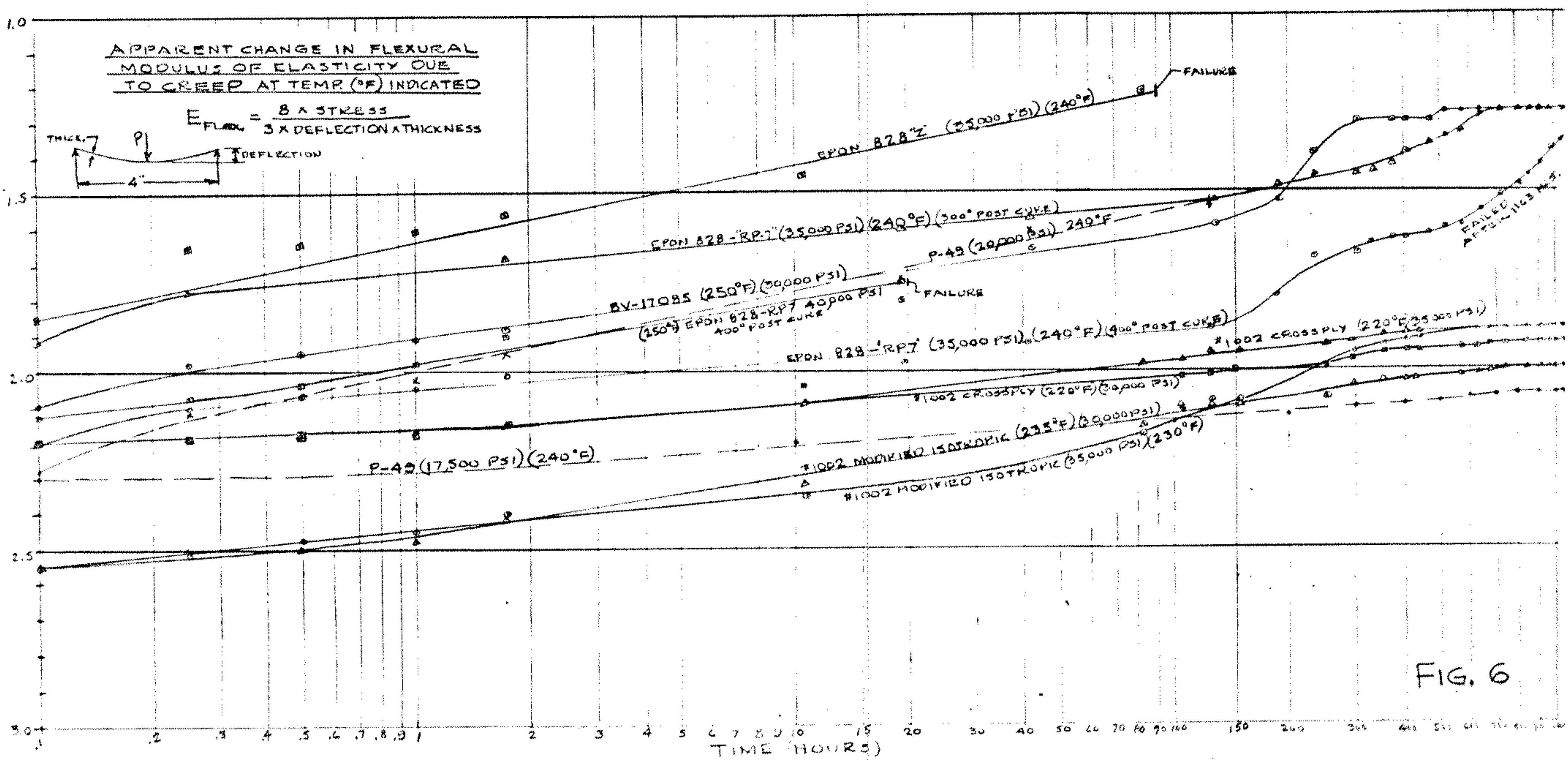
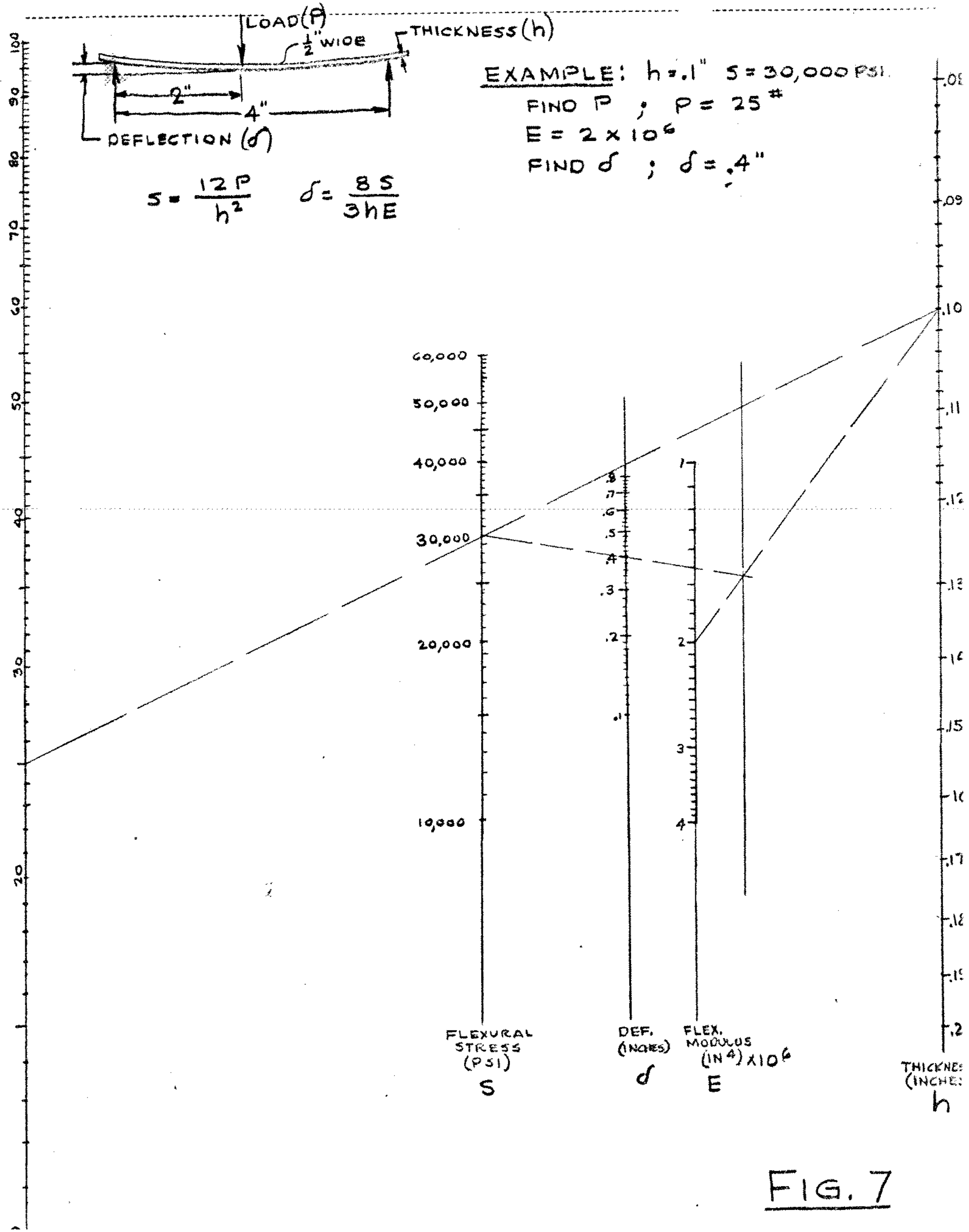

APPARENT CHANGE IN FLEXURAL MODULUS OF ELASTICITY DUE TO CREEP AT TEMP. (°F) INDICATED
E FLEX = 8 x STRESS / 3 x DEFLECTION x THICKNESS
THICK.
P
DEFLECTION
4"
FAILURE
EPON 828 "Z" (35,000 PSI) (240°F)
EPON 828 - "RP-7" (35,000 PSI) (240°F) (300° POST CURE)
P-49 (20,000 PSI) 240°F
BV-17085 (250°F) (30,000 PSI)
(250°F) EPON 828-RP7 40,000 PSI 400° POST CURE
FAILURE
EPON 828 - "RP7" (35,000 PSI) (240°F) (400° POST CURE)
#1002 CROSSPLY (220°F) (35,000 PSI)
#1002 CROSSPLY (220°F) (30,000 PSI)
P-49 (17,500 PSI) (240°F)
#1002 MODIFIED ISOTROPIC (235°F) (30,000 PSI)
#1002 MODIFIED ISOTROPIC (35,000 PSI) (230°F)
FAILED
1.0
1.5
2.0
2.5
3.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
10
15
20
30
40
50
60
70
80
90
100
150
200
300
400
TIME (HOURS)

FIG. 6

BY .... DATE .... SUBJECT FLEXURAL TEST .... SHEET NO. .... OF ....

CHKD. BY .... DATE .... SPECIMAN NOMOGRAPH .... JOB NO. ....



EXAMPLE: $h = .1''$ $S = 30{,}000$ PSI

FIND P ; $P = 25\#$

$E = 2 \times 10^6$

FIND δ ; $\delta = .4''$

$$S = \frac{12P}{h^2} \qquad \delta = \frac{8S}{3hE}$$

FIG. 7

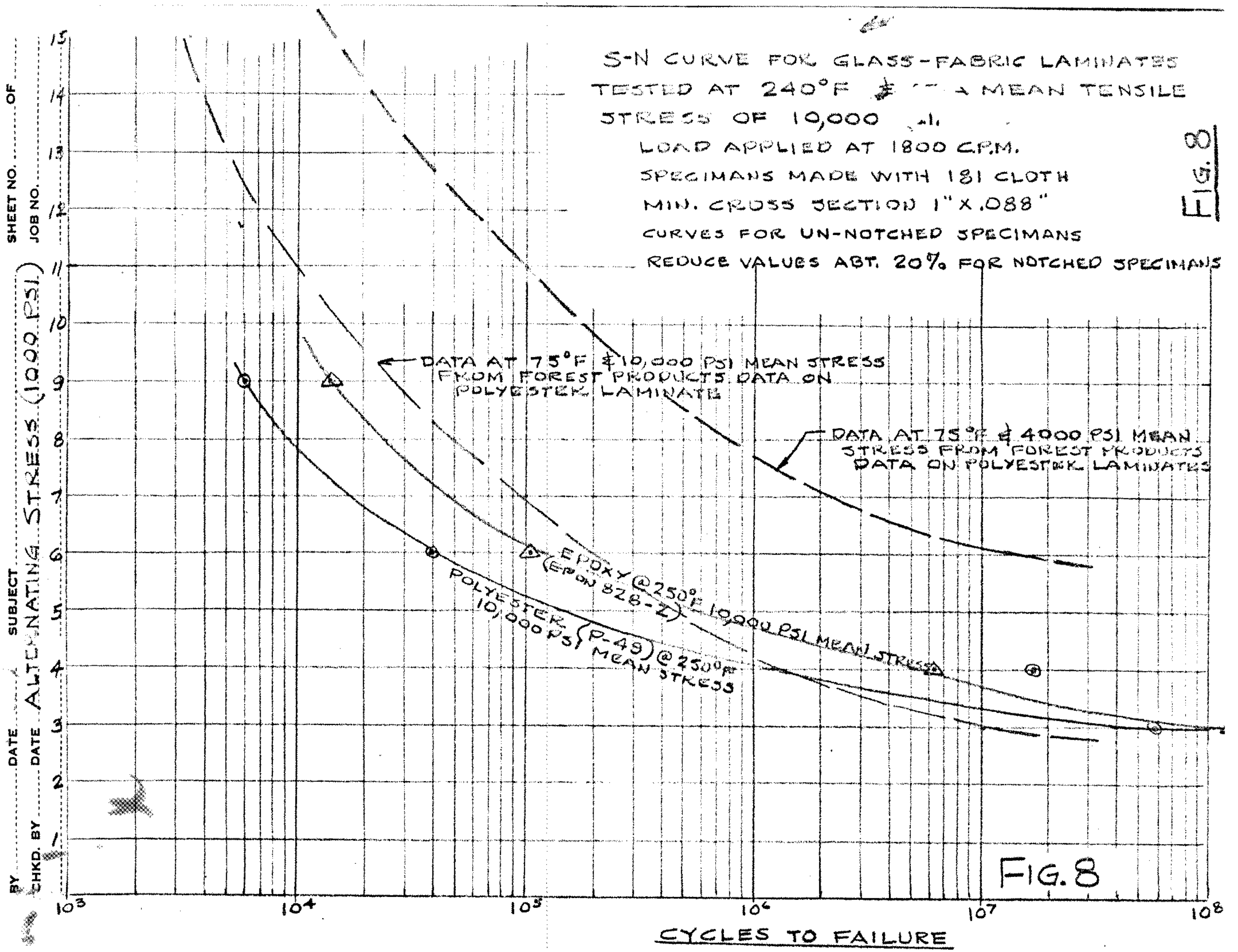

S-N CURVE FOR GLASS-FABRIC LAMINATES
TESTED AT 240°F &
A MEAN TENSILE
STRESS OF 10,000
LOAD APPLIED AT 1800 C.P.M.
SPECIMANS MADE WITH 181 CLOTH
MIN. CROSS SECTION 1" X .088"
CURVES FOR UN-NOTCHED SPECIMANS
REDUCE VALUES ABT. 20% FOR NOTCHED SPECIMANS
DATA AT 75°F & 10,000 PSI MEAN STRESS FROM FOREST PRODUCTS DATA ON POLYESTER LAMINATE
DATA AT 75°F & 4000 PSI MEAN STRESS FROM FOREST PRODUCTS DATA ON POLYESTER LAMINATES
EPOXY @ 250°F 10,000 PSI MEAN STRESS
(EPON 828-Z)
POLYESTER (P-49) @ 250°F
10,000 PSI MEAN STRESS
ALTERNATING STRESS (1000 PSI)
CYCLES TO FAILURE
10^3
10^4
10^5
10^6
10^7
10^8
SHEET NO. ...... OF ......
JOB NO.
SUBJECT
DATE
BY
CHKD. BY
DATE
FIG. 8

FIG. 8